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Kato

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(54) **PROJECTION TYPE DISPLAY APPARATUS AND METHOD OF COOLING LIGHT SOURCE**

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CPC ***G03B 21/16*** (2013.01); ***G03B 21/2033*** (2013.01)

(58) **Field of Classification Search**
CPC G03B 21/16; G03B 21/2033; H05B 33/0869; H05B 33/0872; H05B 33/0875; H05B 33/0833; H05B 33/0845; H05B 33/0854
USPC ..... 353/52, 31, 54, 57; 315/113, 291, 274, 315/307, 308, 309, 310, 311, 185 S; 372/34; 355/30; 362/382, 234, 253, 800; 345/39
See application file for complete search history.

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(57) **ABSTRACT**

There is provided a projection-type display apparatus which solves the problem that when an amount of electric power applied to light sources is adjusted, the amount of electric power involved in the cooling of LEDs becomes greater than necessary. Coolers (**107**R, **107**G, **107**B) cool light sources (**103**R, **103**G, **103**B). Light sensor (**111**) detects the brightness of a surrounding area. Light case temperature detectors (**112**R, **112**G, **112**B) detect case temperatures which are the temperatures of cases of light sources (**103**R, **103**G, **103**B). Light source forward voltage detectors (**113**R, **113**G, **113**B) detect forward voltages of light sources (**103**R, **103**G, **103**B). Light source forward current detectors (**114**R, **114**G, **114**B) detect forward currents of light sources (**103**R, **103**G, **103**B). Adjuster (**117**) adjusts the amount of cooling power of coolers (**107**R, **107**G, **107**B) based on the forward voltage, the forward current, and the case temperatures.

3 Claims, 9 Drawing Sheets

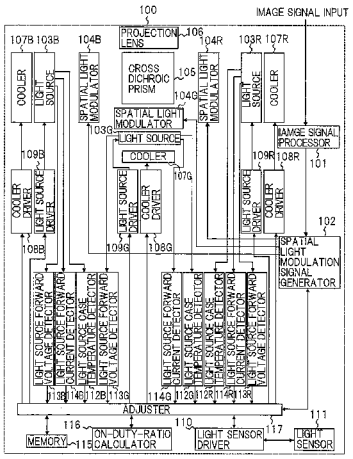

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Fig.1

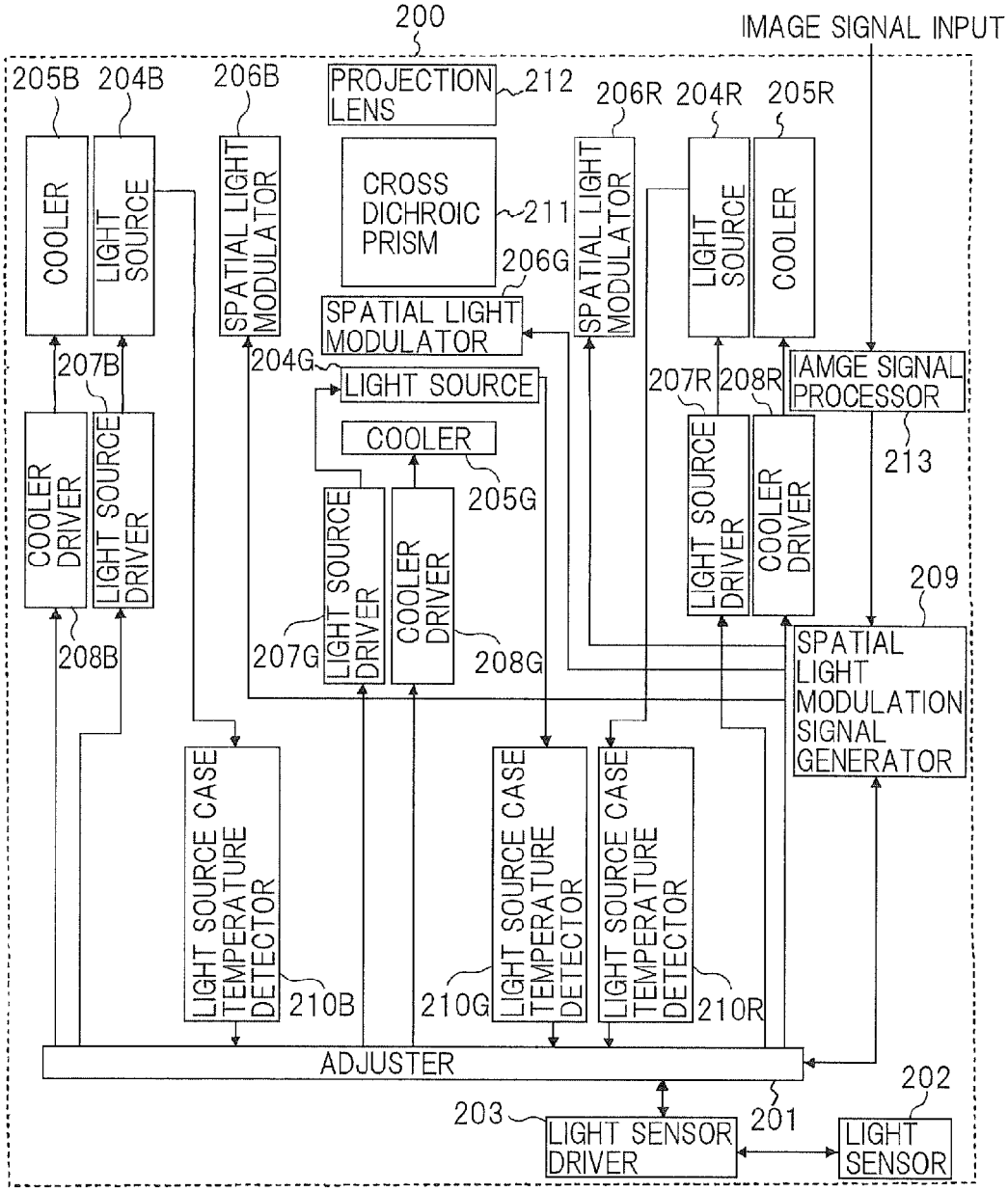

200
IMAGE SIGNAL INPUT
205B
204B
206B
PROJECTION LENS
212
206R
204R
205R
COOLER
LIGHT SOURCE
SPATIAL LIGHT MODULATOR
CROSS DICHROIC PRISM
211
206G
SPATIAL LIGHT MODULATOR
LIGHT SOURCE
COOLER
207B
204G
LIGHT SOURCE
207R
208R
IAMGE SIGNAL PROCESSOR
COOLER
213
COOLER DRIVER
LIGHT SOURCE DRIVER
LIGHT SOURCE DRIVER
COOLER DRIVER
LIGHT SOURCE DRIVER
COOLER DRIVER
209
208B
207G
208G
SPATIAL LIGHT MODULATION SIGNAL GENERATOR
LIGHT SOURCE CASE TEMPERATURE DETECTOR
LIGHT SOURCE CASE TEMPERATURE DETECTOR
LIGHT SOURCE CASE TEMPERATURE DETECTOR
210B
210G
210R
ADJUSTER
202
203
201
LIGHT SENSOR DRIVER
LIGHT SENSOR

Fig.2

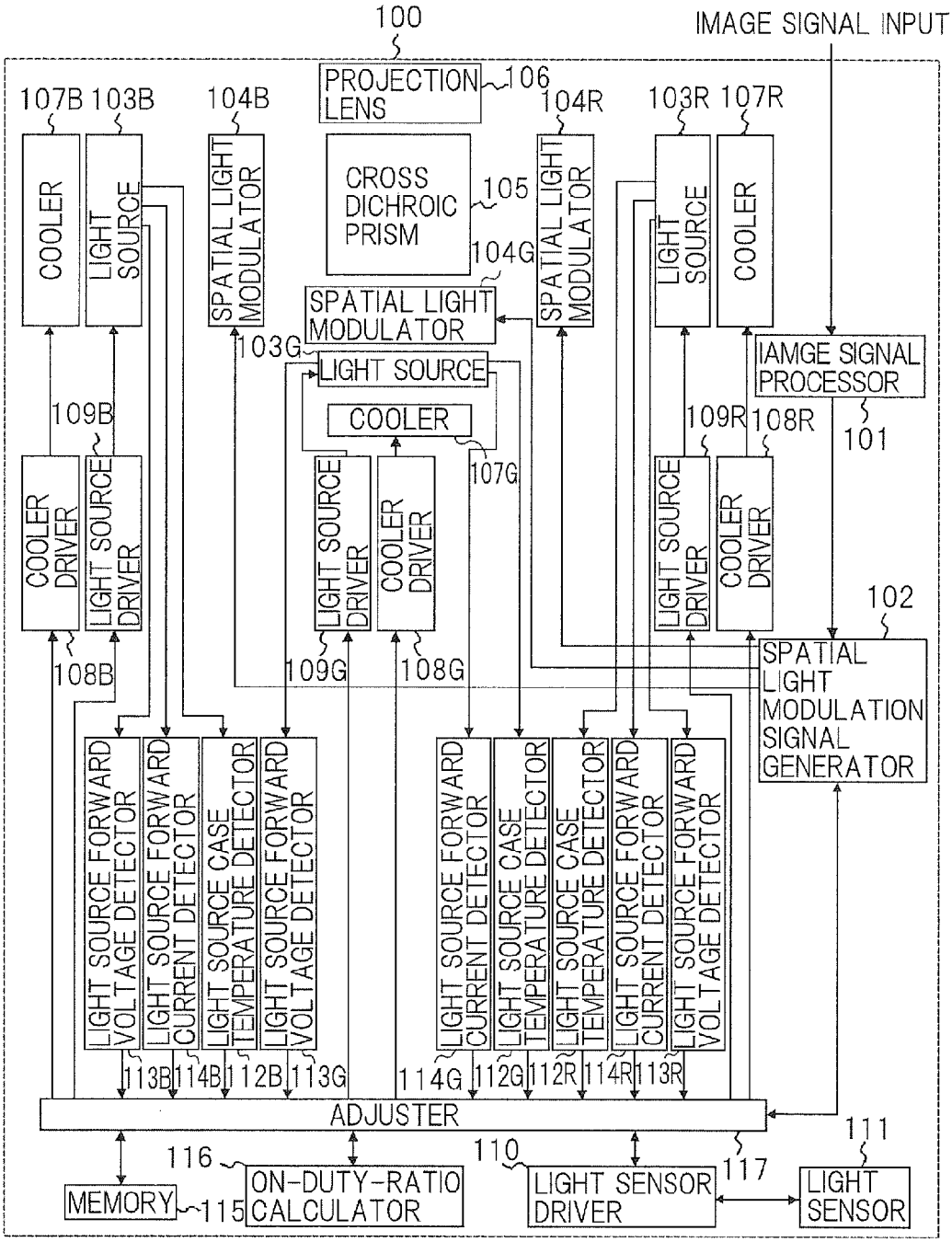

100
IMAGE SIGNAL INPUT
PROJECTION LENS
106
107B
103B
104B
104R
103R
107R
COOLER
LIGHT SOURCE
SPATIAL LIGHT MODULATOR
CROSS DICHROIC PRISM
105
104G
SPATIAL LIGHT MODULATOR
LIGHT SOURCE
COOLER
103G
LIGHT SOURCE
COOLER
IAMGE SIGNAL PROCESSOR
101
109B
109R
108R
107G
COOLER DRIVER
LIGHT SOURCE DRIVER
LIGHT SOURCE DRIVER
COOLER DRIVER
LIGHT SOURCE DRIVER
COOLER DRIVER
102
108B
109G
108G
SPATIAL LIGHT MODULATION SIGNAL GENERATOR
LIGHT SOURCE FORWARD VOLTAGE DETECTOR
LIGHT SOURCE FORWARD CURRENT DETECTOR
LIGHT SOURCE CASE TEMPERATURE DETECTOR
LIGHT SOURCE FORWARD VOLTAGE DETECTOR
LIGHT SOURCE FORWARD CURRENT DETECTOR
LIGHT SOURCE CASE TEMPERATURE DETECTOR
LIGHT SOURCE FORWARD CURRENT DETECTOR
LIGHT SOURCE FORWARD VOLTAGE DETECTOR
113B
114B
112B
113G
114G
112G
112R
114R
113R
ADJUSTER
111
116
110
117
MEMORY
115
ON-DUTY-RATIO CALCULATOR
LIGHT SENSOR DRIVER
LIGHT SENSOR

Fig.3

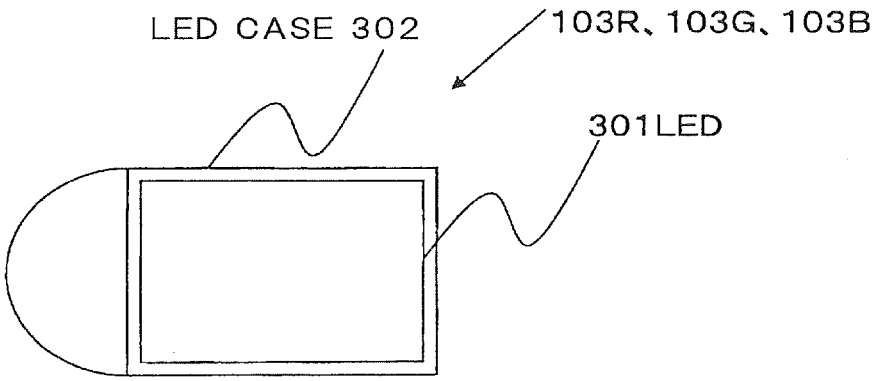


Fig.4

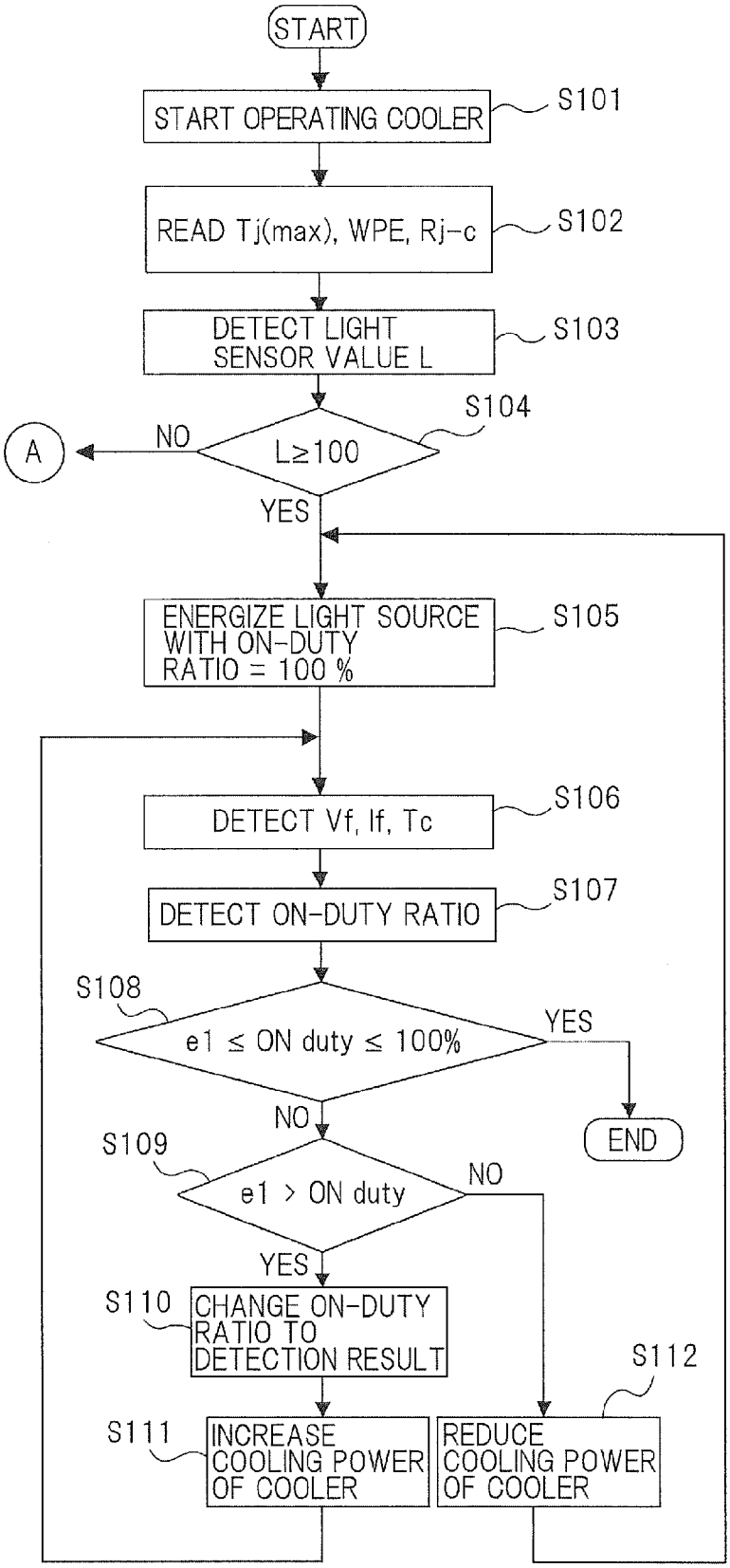

START
START OPERATING COOLER
S101
READ Tj(max), WPE, Rj-c
S102
DETECT LIGHT SENSOR VALUE L
S103
S104
L≥100
NO
A
YES
ENERGIZE LIGHT SOURCE WITH ON-DUTY RATIO = 100 %
S105
DETECT Vf, If, Tc
S106
DETECT ON-DUTY RATIO
S107
S108
e1 ≤ ON duty ≤ 100%
YES
END
NO
S109
e1 > ON duty
NO
YES
S110
CHANGE ON-DUTY RATIO TO DETECTION RESULT
S112
S111
INCREASE COOLING POWER OF COOLER
REDUCE COOLING POWER OF COOLER

Fig.5

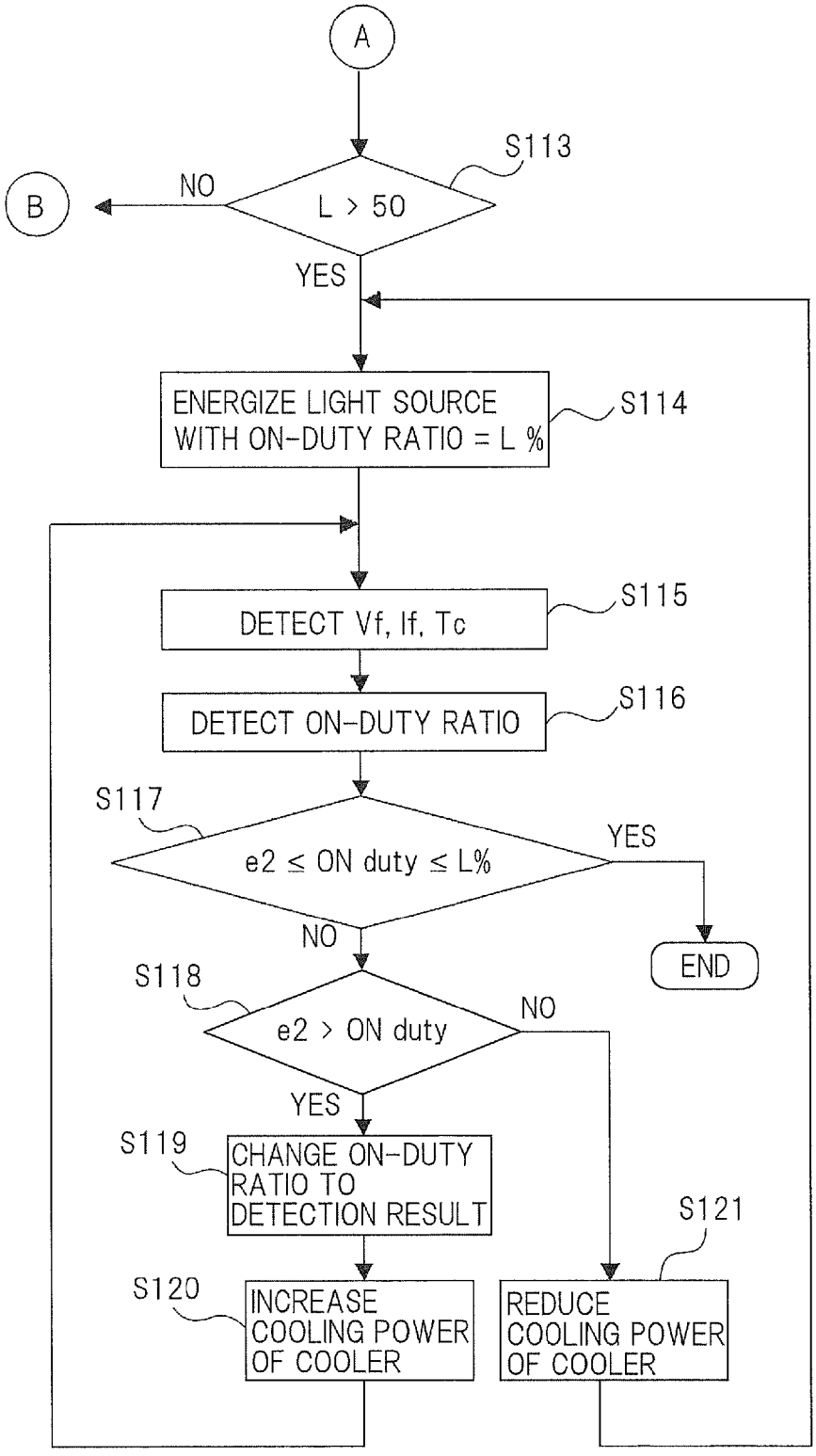

A
S113
NO
B
L > 50
YES
ENERGIZE LIGHT SOURCE WITH ON-DUTY RATIO = L %
S114
DETECT Vf, If, Tc
S115
DETECT ON-DUTY RATIO
S116
S117
e2 ≤ ON duty ≤ L%
YES
NO
END
S118
e2 > ON duty
NO
YES
S119
CHANGE ON-DUTY RATIO TO DETECTION RESULT
S121
S120
INCREASE COOLING POWER OF COOLER
REDUCE COOLING POWER OF COOLER

Fig.6

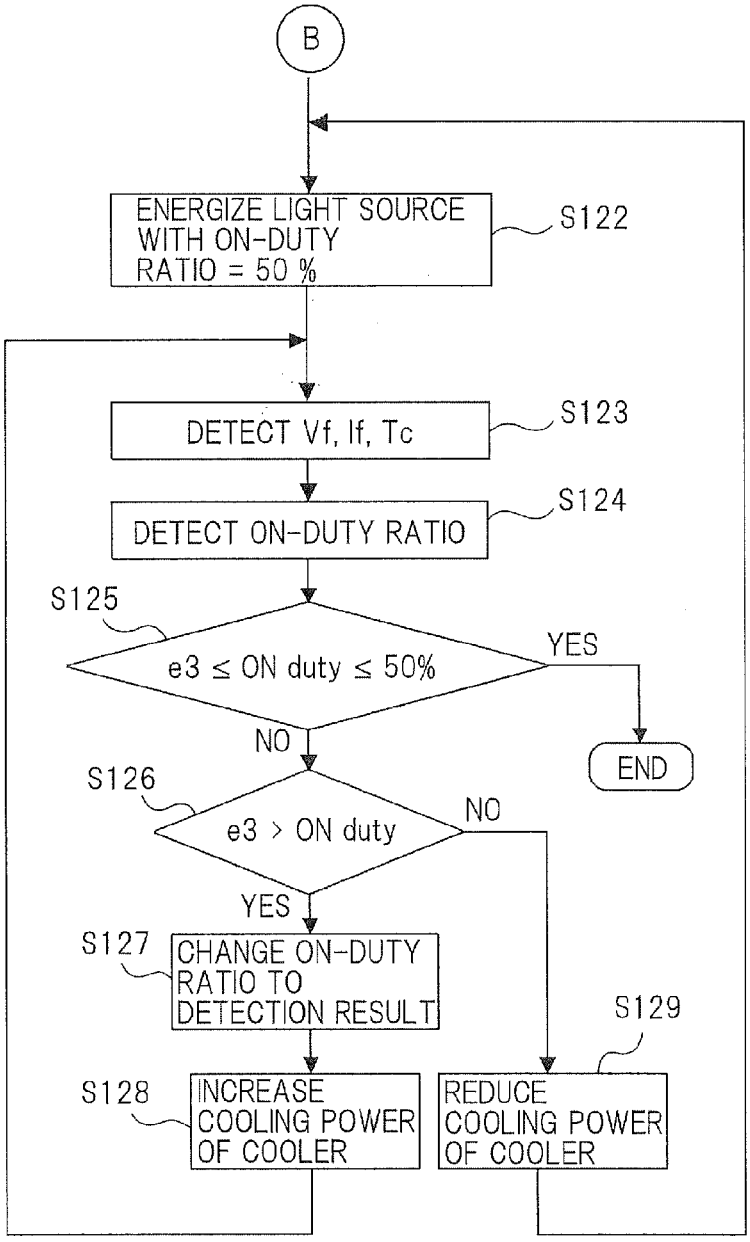
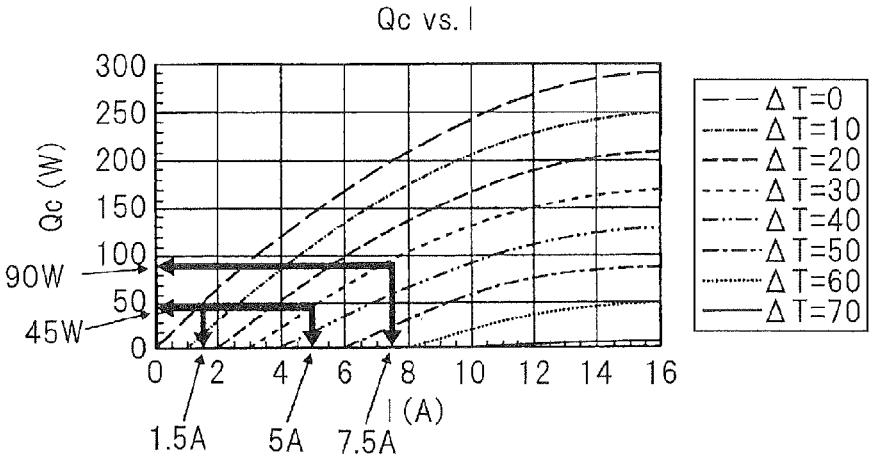


Fig.7

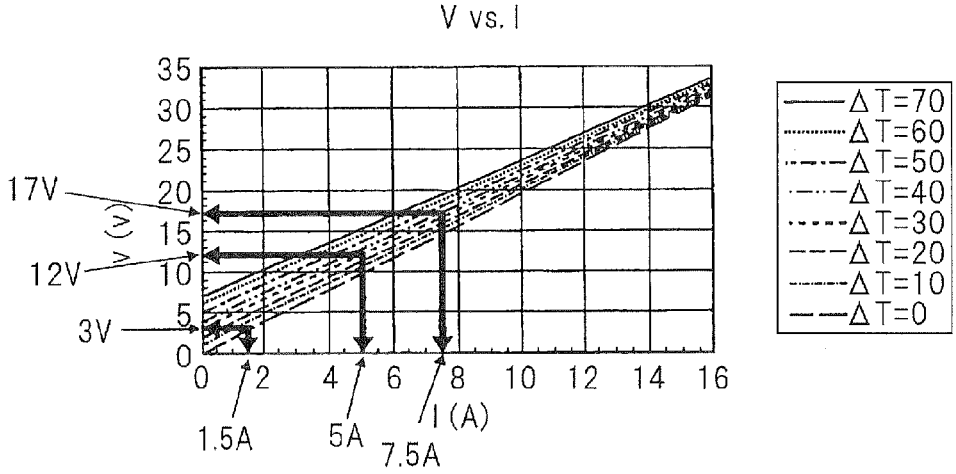
	RED(R) LED	GREEN(G) LED	BLUE(B) LED
Tj (max)	110℃	170℃	170℃
WPE	15%	5%	10%
Rj-c	1℃/W	1℃/W	1℃/W

Fig.8



Th: HEAT RADIATION SIDE TEMPERATURE
Qc: ENDOTHERMIC QUANTITY
I: INPUT CURRENT
ΔT: TEMPERATURE DIFFERENCE BETWEEN HEAT RADIATION SIDE AND HEAT ABSORPTION SIDE

Fig.9



Th: HEAT RADIATION SIDE TEMPERATURE
Qc: ENDOTHERMIC QUANTITY
I: INPUT CURRENT
ΔT: TEMPERATURE DIFFERENCE BETWEEN HEAT RADIATION SIDE AND HEAT ABSORPTION SIDE

Fig.10

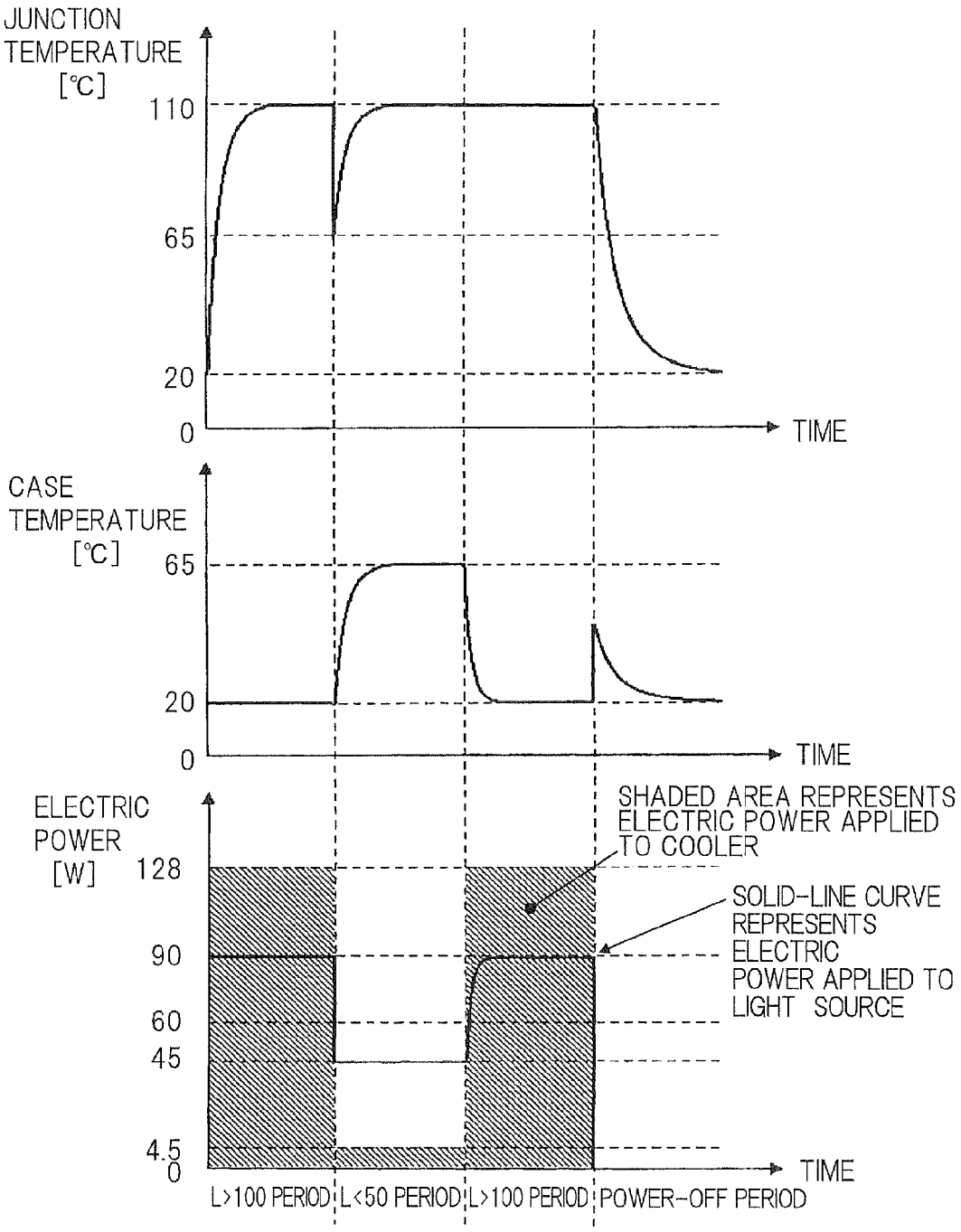
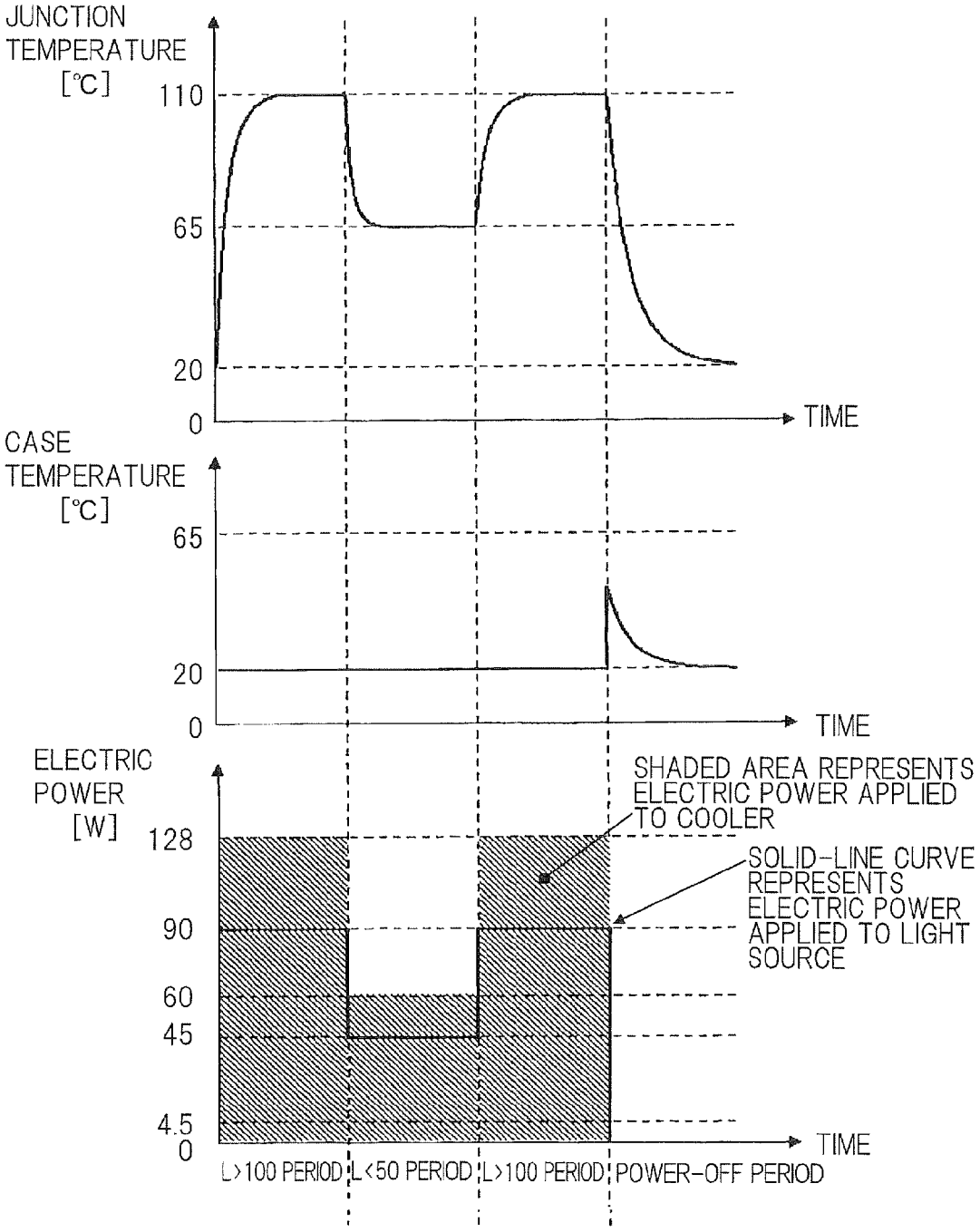

JUNCTION TEMPERATURE [℃]
110
65
20
0
TIME
CASE TEMPERATURE [℃]
65
20
0
TIME
ELECTRIC POWER [W]
128
90
60
45
4.5
0
TIME
SHADED AREA REPRESENTS ELECTRIC POWER APPLIED TO COOLER
SOLID-LINE CURVE REPRESENTS ELECTRIC POWER APPLIED TO LIGHT SOURCE
L>100 PERIOD
L<50 PERIOD
L>100 PERIOD
POWER-OFF PERIOD

Fig.11


JUNCTION TEMPERATURE [℃]
110
65
20
0
TIME
CASE TEMPERATURE [℃]
65
20
0
TIME
ELECTRIC POWER [W]
128
90
60
45
4.5
0
TIME
SHADED AREA REPRESENTS ELECTRIC POWER APPLIED TO COOLER
SOLID-LINE CURVE REPRESENTS ELECTRIC POWER APPLIED TO LIGHT SOURCE
L>100 PERIOD
L<50 PERIOD
L>100 PERIOD
POWER-OFF PERIOD

PROJECTION TYPE DISPLAY APPARATUS AND METHOD OF COOLING LIGHT SOURCE

TECHNICAL FIELD

The present invention relates to a projection-type display apparatus using LEDs (Light-Emitting Diodes) and a method of cooling a light source thereof.

BACKGROUND ART

Projection-type display apparatus for projecting an image onto a screen have heretofore often employed a high-pressure mercury lamp as a light source. In recent years, attention has been paid to projection-type display apparatus employing LEDs instead of high-pressure mercury lamps.

LEDs are advantageous in that their brightness can be adjusted more quickly than high-pressure mercury lamps. Therefore, projection-type display apparatus which employ LEDs as a light source are capable of adjusting the brightness of a projected image depending on the brightness of the surrounding area by adjusting the brightness of the LEDs depending on the brightness of the surrounding area. Since the LEDs can be prevented from being energized for a higher level of brightness than necessary, the power consumption of the projection-type display apparatus is reduced.

The LEDs have a low power conversion efficiency (WPE: Wall Plug Efficiency), which represents the ratio of light output power to applied electric power, in the range from about 5% to 15%. Much of the applied electric power is converted into heat, which tends to increase the junction temperature Tj of the LEDs. If the junction temperature Tj of the LEDs goes higher than a certain level, then the light output power of the LEDs is abruptly reduced. Consequently, the projection-type display apparatuses which employ LEDs as a light source usually cool the LEDs so that the junction temperature Tj of the LEDs will not exceed a maximum junction temperature Tj(max). The LEDs are often cooled by a cooling means such as a Peltier device that is able to adjust the cooling power depending on the amount of applied electric power (see Patent document 1).

FIG. **1** is a block diagram showing the configuration of a projection-type display apparatus having a cooling means for cooling LEDs and capable of changing the brightness of the LEDs depending on the brightness of the surrounding area.

As shown in FIG. **1**, projection-type display apparatus **200** includes light sources **204**R, **204**G, **204**B for emitting a red beam, a green beam, and a blue beam, respectively, coolers **205**R, **205**G, **205**B for cooling respective light sources **204**R, **204**G, **204**B, and adjuster **201** for adjusting the amount of electric power applied to light sources **204**R, **204**G, **204**B and the amount of electric power applied to coolers **205**R, **205**G, **205**B.

Each of light sources **204**R, **204**G, **204**B comprises an LED and an LED case housing the LED. Each of coolers **205**R, **205**G, **205**B comprises a Peltier device.

Adjuster **201** adjusts the brightness of each LED by adjusting the amount of applied light source electric power W, which is the amount of electric power applied to the LED, depending on the detection result of light sensor **202** that detects the brightness of the surrounding area.

Adjuster **201** also adjusts the amount of applied cooler electric power, which is the amount of electric power applier to coolers **205**R, **205**G, **205**B, depending on the detection results of light source case temperature detectors **210**R, **210**G, **210**B that detect case temperatures Tc of the LED cases of respective light sources **204**R, **204**G, **204**B.

Generally, it is known that the equation "Tj=If×Vf×(1−WPE/100)×Rj−c+Tc" is satisfied between the junction temperature Tj of the LED and the case temperature Tc of the LED case where if represents a forward current of the LED, Vf a forward voltage of the LED, WPE, a power conversion efficiency of the LED, and Rj−c the thermal resistance between the LED junction and the LED case. In the above equation, the product If×Vf of the forward current If and the forward voltage Vf represents the amount of applied power supply electric power W that is applied to the LED. The power conversion efficiency WPE and the thermal resistance Rj−c are usually regarded as constants that are determined for each LED.

As can be seen from the above equation, if the amount of applied power supply electric power W is constant, then the maximum case temperature which is the case temperature Tc at the time the junction temperature Tj is the maximum junction temperature Tj(max) is uniquely determined. If the amount of applied cooler electric power is adjusted so that the case temperature Tc becomes the maximum case temperature, then the junction temperature Tj will not exceed the maximum junction temperature Tj(max).

However, with the projection-type display apparatus **200**, since the amount of applied power supply electric power W changes depending on the brightness of the surrounding area, the maximum case temperature also changes. More specifically, as the amount of applied power supply electric power W becomes greater, the maximum case temperature goes lower. In order that the junction temperature Tj will not exceed the maximum junction temperature Tj(max) even if the maximum case temperature changes, adjuster **201** adjusts the amount of applied cooler electric power so that the case temperature Tc is equalized to the maximum case temperature when the amount of applied power supply electric power W is of an upper limit value.

BACKGROUND ART DOCUMENTS

Patent Documents

Patent document 1: JP2004-342557A

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

With projection-type display apparatus **200** shown in FIG. **1**, as the amount of applied power supply electric power W is adjusted depending on the brightness of the surrounding area, the amount of applied power supply electric power W may occasionally be lower than the upper limit value. The maximum junction temperature at this time is lower than the maximum junction temperature at the time the applied power supply electric power W is of the upper limit value. Therefore, by lowering the cooling capability of the Peltier device by lowering the amount of applied cooler electric power, the junction temperature Tj can be prevented from exceeding the maximum junction temperature Tj(max).

However, inasmuch as projection-type display apparatus **200** adjusts the amount of applied cooler electric power so that the case temperature Tc is always equal to the maximum case temperature at the time the amount of applied power supply electric power W is of the upper limit value, the amount of electric power consumed to cool the LEDs is greater than necessary.

It is an object of the present invention to provide a projection-type display apparatus which is capable of solving the above problem in which the amount of electric power consumed to cool the LEDs is greater than necessary when the amount of applied light source electric power is adjusted.

Means for Solving the Problems

According to the present invention, there is provided a projection-type display apparatus for projecting a beam from an LED to display an image, comprising a cooler for cooling said LED, a light detector for detecting the brightness of a surrounding area, a voltage detector for detecting the forward voltage of said LED, a current detector for detecting the forward current of said LED, a temperature detector for detecting the case temperature which represents the temperature of the case of said LED, and a controller for adjusting the brightness of said LED based on said brightness of the surrounding area and adjusting the amount of cooling power of said cooler based on said forward voltage, said forward current, and said case temperature.

According to the present invention, there is also provided a method of cooling a light source of a projection-type display apparatus for projecting a beam from an LED to display an image, comprising detecting the brightness of a surrounding area, detecting a forward voltage of said LED, detecting a forward current of said LED, detecting a case temperature which represents the temperature of a case of said LED, and cooling said LED with an amount of cooling power depending on said forward voltage, said forward current, and said case temperature.

Effects of the Invention

According to the present invention, the amount of electric power involved in the cooling of the LEDs can be of an appropriate value even when the amount of applied light source electric power is adjusted.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing the configuration of a projection-type display apparatus according to the background art;

FIG. **2** is a block diagram showing the configuration of a projection-type display apparatus according to an exemplary embodiment of the present invention;

FIG. **3** is a view showing a configurational example of a light source;

FIG. **4** is a flowchart of an example of an operation sequence of the projection-type display apparatus according to the exemplary embodiment;

FIG. **5** is a flowchart of the example of the operation sequence of the projection-type display apparatus according to the exemplary embodiment;

FIG. **6** is a flowchart of the example of the operation sequence of the projection-type display apparatus according to the exemplary embodiment;

FIG. **7** is a diagram showing an example of characteristics of LEDs;

FIG. **8** is a diagram showing an example of endothermic characteristics representative of the relationship between current I and endothermic quantity Q of a Peltier device;

FIG. **9** is a diagram showing an example of current vs. voltage characteristics representative of the relationship between current I and voltage V of the Peltier device;

FIG. **10** is a diagram showing an example of changes in the amount of electric power applied to coolers of the projection-type display apparatus according to the exemplary embodiment; and

FIG. **11** is a diagram showing an example of changes in the amount of electric power applied to coolers of the projection-type display apparatus according to the background art.

MODE FOR CARRYING OUT THE INVENTION

An exemplary embodiment of the present invention will be described below with reference to the drawings. In the description which follows, those parts which have identical functions are denoted by identical reference characters, and may not be described in detail.

FIG. **2** is a block diagram showing the configuration of a projection-type display apparatus according to an exemplary embodiment of the present invention. As shown in FIG. **2**, projection-type display apparatus **100** includes image signal processor **101**, spatial light modulation signal generator **102**, light sources **103**R, **103**G, **103**B, spatial light modulators **104**R, **104**G, **104**B, cross dichroic prism **105**, projection lens **106**, coolers **107**R, **107**G, **107**B, cooler drivers **108**R, **108**G, **108**B, light source drivers **109**R, **109**G, **109**B, light sensor driver **110**, light sensor **111**, light source case temperature detectors **112**R, **112**G, **112**B, light source forward voltage detectors **113**R, **113**G, **113**B, light source forward current detectors **114**R, **114**G, **114**B, memory **115**, ON-Duty-Ratio calculator **116**, and adjuster **117**.

Image signal processor **101** is supplied with an image signal and performs various image signal processing processes such as resolution conversion on the supplied image signal.

Spatial light modulation signal generator **102** generates spatial light modulation signals for spatially modulating light depending on the supplied image signal that has been processed by image signal processor **101**, and output the generated spatial light modulation signals to spatial light modulators **104**R, **104**G, **104**B.

As shown in FIG. **3**, each of light sources **103**R, **103**G, **103**B comprises LED **301** and LED case **302** housing LED **301** therein.

Light sources **103**R, **103**G, **103**B emit light beams at intensities depending on the amount of applied light source electric power supplied from light source drivers **109**R, **109**G, **109**B. The light beams emitted from light sources **103**R, **103**G, **103**B have respective different wavelengths. It is assumed hereinbelow that light source **103**R emits a red beam in a red wavelength range, light source **103**G a green beam in a green wavelength range, and light source **103**G a blue beam in a blue wavelength range. An LED used in light source **103**R will be referred to as a red LED, an LED used in light source **103**G as a green LED, and an LED used in light source **103**B as a blue LED.

Spatial light modulators **104**R, **104**G, **104**B spatially modulate the light beams from respective light sources **103**R, **103**G, **103**B with the spatial light modulation signals from spatial light modulation signal generator **102**, and emits the spatially modulated light beams.

Cross dichroic prism **105** combines the light beams from spatial light modulators **104**R, **104**G, **104**B into a combined light beam, and emits the combined light beam.

Projection lens **106** projects the combined light beam from cross dichroic prism **105** onto a screen (not shown) to display an image on the screen.

Each of coolers **107**R, **107**G, **107**B comprises a Peltier device. Coolers **107**R, **107**G, **107**B cools light sources **103**R,

103G, 103B with cooling power depending on the amount of applied cooler electric power that is supplied from respective cooler drivers 108R, 108G, 108B.

Cooler drivers 108R, 108G, 108B applies the amount of cooler electric power indicated by cooler control signals from adjuster 117 to coolers 107R, 107G, 107B, adjusting the amount of cooling power with which coolers 107R, 107G, 107B cool light sources 103R, 103G, 103B.

Light source drivers 109R, 109G, 109B energize respective light sources 103R, 103G, 103B at levels of brightness represented by light source control signals from adjuster 117.

According to the present exemplary embodiment, light source drivers 109R, 109G, 109B apply pulsed electric power as the amount of applied light source electric power to respective light sources 103R, 103G, 103B, thereby energizing light sources 103R, 103G, 103B. The levels of brightness of respective light sources 103R, 103G, 103B change depending on the duty ratio of pulsed electric power. Therefore, the light source control signals represent the duty ratios, and light source drivers 109R, 109G, 109B apply pulsed electric power at the duty ratios indicated by the light source control signals to respective light sources 103R, 103G, 103B.

Light sensor driver 110 applies sensor electric power to light sensor 111.

Light sensor 111 comprises a light detector which is energized by the sensor electric power from light sensor driver 110 and which detects the brightness in the surrounding area, i.e., outside projection-type display apparatus 100.

Light source case temperature detectors 112R, 112G, 112B detect case temperatures Tc, which are temperatures of the LED cases 302 of respective light sources 103R, 103G, 103B.

Light source forward voltage detectors 113R, 113G, 113B detect forward voltages Vf of LEDs 301 of respective light sources 103R, 103G, 103B.

Light source forward current detectors 114R, 114G, 114B detect forward currents If of LEDs 301 of respective light sources 103R, 103G, 103B.

Memory 115, On-Duty-Ratio calculator 116, and adjuster 117 make up a controller. The controller determines duty ratios of pulsed electric power to be applied to respective light sources 103R, 103G, 103B depending on the brightness of the surrounding area that is detected by light sensor 111, and output light source control signals representative of the determined duty ratios to adjust the levels of brightness of respective light sources 103R, 103G, 103B.

The controller also the amount of determines applied cooler electric power to be applied to coolers 107R. 107G, 107B based on the case temperatures Tc detected by light source case temperature detectors 112R, 112G, 112B, the forward voltages Vf detected by light source forward voltage detectors 113R, 113G, 113B, and the forward currents If detected by light source forward current detectors 114R, 114G, 114B, and output cooler control signals representative of the determined applied cooler electric power to cooler drivers 108R, 108G, 108B to adjust the cooling power of coolers 107R, 107G, 107B.

Memory 51 stores characteristic information representative of the characteristics of LEDs 301 used in respective light sources 103R, 103G, 103B. The characteristic information indicates, as the characteristics of LEDs 301, the maximum junction temperature Tj(max), the power conversion efficiency WPE, and the thermal resistance Rf-c between the LED junction and the LED case.

On-Duty-Ratio calculator 116 calculates, as "On-Duty Ratio" of each LED 301, the ratio of the difference between the maximum junction temperature Tj(max) and the case temperature Tc to the difference between the junction temperature Tj and the case temperature Tc, based on the characteristic information of LED 301, the case temperature Tc of LED case 302, forward voltage Vf and forward current If of LED 301.

Adjuster 117 outputs the light source control signals representative of the duty ratios depending on the brightness of the surrounding area to respective light sources 103R, 103G, 103B to adjust the levels of brightness of respective light sources 103R, 103G, 103B.

Adjuster 117 also outputs the cooler control signals representative of the "On-Duty Ratios" calculated by On-Duty-Ratio calculator 116 to cooler drivers 108R, 108G, 108B to adjust the amount of cooling power of coolers 107R, 107G, 107B.

More specifically, when the LEDs are energized, adjuster 117 sets the amount of applied cooler electric power represented by the cooler control signals to a preset value. Thereafter, if the "On-Duty Ratios" are greater than the upper limit value of an allowable range determined depending on the brightness of the LEDs, then adjuster 117 reduces the amount of applied cooler electric power, and if the "On-Duty Ratios" are smaller than the lower limit value of the allowable range, then adjuster 117 increases the amount of applied cooler electric power. Therefore, if the "On-Duty Ratios" are greater than the upper limit value of the allowable range, adjuster 117 reduces the amount of cooling power of coolers 107R, 107G, 107B, and if the "On-Duty Ratios" are smaller than the lower limit value of the allowable range, adjuster 117 increases the amount of cooling power of coolers 107R, 107G, 107B.

Operation of projection-type display apparatus 100 will be described below.

FIGS. 4 through 6 are flowcharts of a light source control process of projection-type display apparatus 100. Since the same operation sequence is carried out for light sources 103R, 103G, 103B, the light source control process for light source 103R will be described below.

When the power supply of projection-type display apparatus 100 is turned on, adjuster 117 outputs a cooler control signal representative of predetermined the amount of applied cooler electric power to enable cooler driver 108R to start operating cooler 107R (step S101).

Then, adjuster 117 reads the characteristic information (maximum junction temperature Tj(max)), the power conversion efficiency WPE, and the thermal resistance Rf-c of light source 103R from memory 115 (step S102).

Thereafter, adjuster 117 outputs a drive signal to light sensor driver 110 to enable light sensor driver 110 to energize light sensor 111. Light sensor 111 detects the brightness of the surrounding area, and outputs a detection result L to adjuster 117 (step S103).

When adjuster 117 receives the detection result L, it judges whether or not the detection result L is equal to or greater than a predetermined first threshold value (hereinafter represented by "100" for illustrative purposes) (step S104). If the detection result L is equal to or greater than the first threshold value "100", then adjuster 117 outputs a light source control signal representative of a duty ratio=100% to light source driver 109A, which energizes light source 103R at the maximum brightness (step S105).

When light source 103R is energized, light source case temperature detector 112R detects a case temperature Tc of light source 103R and outputs it to adjuster 117. Light source forward voltage detector 113R detects a forward voltage Vf of light source 103R and outputs it to adjuster 117. Light source forward current detector 114R detects a forward current If of light source 103R and outputs it to adjuster 117 (step S106).

When adjuster **117** receives the case temperature Tc, the forward voltage Vf, and the forward current If, it outputs the case temperature Tc, the forward voltage Vf, the forward current If, and the characteristic information read in step **S102** to On-Duty-Ratio calculator **116**.

When On-Duty-Ratio calculator **116** receives the characteristic information, the case temperature Tc, the forward voltage Vf, and the forward current If, it calculates an "On-Duty Ratio" of light source **103**R (step **S107**).

More specifically, On-Duty-Ratio calculator **116** calculates an "On-Duty Ratio" of light source **103**R according to the equation 1:

$$\text{ON_duty} = \frac{Tj(\max) - Tc}{Vf \times If \times \left(1 - \frac{WPE}{100}\right) \times Rj - c} \times 100 \qquad \text{[Equation 1]}$$

In the equation 1, the denominator Vf×If×(1−WPE/100)×Rj−c on the right side becomes the difference Tj−Tc between the junction temperature Tj and the case temperature Tc of the LED in view of the equation about the junction temperature Tj and the case temperature Tc of the LED. In other words, On-Duty-Ratio calculator **116** calculates an "On-Duty Ratio" of light source **103**R based on the junction temperature Tj and the case temperature Tc of the LED, or calculates, as an "On-Duty Ratio" of light source **103**R, the ratio of the difference between the maximum junction temperature Tj(max) and the case temperature Tc of the LED to the difference between the junction temperature Tj and the case temperature Tc of the LED.

After having calculated the "On-Duty Ratio" of light source **103**R, On-Duty-Ratio calculator **116** outputs the calculated "On-Duty Ratio" to adjuster **117**. When adjuster **117** receives the "On-Duty Ratio", it judges whether or not the "On-Duty Ratio" falls in a first allowable range (e1≤On-Duty Ratio≤100%) (step **S108**). The first allowable range has a lower limit value e1 which is a positive value smaller than 100%.

If the "On-Duty Ratio" falls in the first allowable range, then adjuster **117** finishes the light source control process.

If the "On-Duty Ratio" does not fall in the first allowable range, then adjuster **117** judges whether or not the "On-Duty Ratio" is smaller than the lower limit value e1 of the first allowable range (step **S109**).

If the "On-Duty Ratio" is smaller than the lower limit value e1, then adjuster **117** decides that the junction temperature Tj is too high and outputs a light source control signal representative of the "On-Duty Ratio" to light source driver **109**R. Adjuster **117** thus changes the duty ratio of light source **103**R to the "On-Duty Ratio" calculated in step **S108**. Therefore, adjuster **117** reduces the brightness of light source **103**R, and hence reduces the amount of heat generated by light source **103**R (step **S110**).

Thereafter, adjuster **117** outputs a cooler control signal representative of the amount of applied cooler electric power that is greater than the predetermined the amount of applied cooler electric power described above to cooler driver **108**R, which increases the amount of cooler electric power. Adjuster **117** thus can increase the amount of cooling power of cooler **107**R (step **S111**).

Since the case temperature Tc of light source **103**R drops due to the increase in the amount of applied cooler electric power, adjuster **117** calculates an "On-Duty Ratio" of light source **103**R again back in step **S105**. If the calculated "On-Duty Ratio" falls in the first allowable range in step **S108**, then the light source control process is ended.

If adjuster **117** decides that the "On-Duty Ratio" is greater than the lower limit value e1 of the first allowable range in step **S109**, then adjuster **117** decides that the "On-Duty Ratio" is greater than the upper limit value of 100%, and outputs a cooler control signal representative of applied cooler electric power that is smaller than the predetermined applied cooler electric power described above to cooler driver **108**R. Adjuster **117** thus reduces the applied cooler electric power and hence the cooling power of cooler **107**R (step **S112**).

Since the case temperature Tc of light source **103**R rises due to the reduction in the applied cooler electric power, adjuster **117** sets the "On-Duty Ratio" of light source **103**R to 100% back in step **S105**. Thereafter, adjuster **117** calculates an "On-Duty Ratio" of light source **103**R again in step **S107**. If the calculated "On-Duty Ratio" falls in the first allowable range in step **S108**, then the light source control process is finished.

If adjuster **117** decides that the detection result L is smaller than the first threshold value in step **S104**, then adjuster **117** judges whether the detection result L is greater than a second threshold (hereinafter represented by "50" for illustrative purposes) that is smaller than the first threshold value (step **S113**). If the decision result L is greater than the second threshold value, then adjuster **117** outputs a light source control signal representative of a duty ratio=L % to light source driver **109**A, which energizes light source **103**R at the level of brightness which is L % of the maximum brightness (step **S114**). L represents a value in the range from 50 to 100.

When light source **103**R is energized, light source case temperature detector **112**R detects a case temperature Tc of light source **103**R and outputs it to adjuster **117**. Light source forward voltage detector **113**R detects a forward voltage Vf of light source **103**R and outputs it to adjuster **117**. Light source forward current detector **114**R detects a forward current If of light source **103**R and outputs it to adjuster **117** (step **S115**).

When adjuster **117** receives the case temperature Tc, the forward voltage Vf, and the forward current If, it outputs the case temperature Tc, the forward voltage Vf, the forward current If, and the characteristic information read in step **S102** to On-Duty-Ratio calculator **116**.

When On-Duty-Ratio calculator **116** receives the characteristic information, the case temperature Tc, the forward voltage Vf, and the forward current If, it calculates an "On-Duty Ratio" of light source **103**R based on the characteristic information, the case temperature Tc, the forward voltage Vf, and the forward current (step **S116**). The "On-Duty Ratio" is calculated in the same manner as it is calculated in step **S107**.

After having calculated the "On-Duty Ratio" of light source **103**R, On-Duty-Ratio calculator **116** outputs the calculated "On-Duty Ratio" to adjuster **117**. When adjuster **117** receives the "On-Duty Ratio", it judges whether or not the "On-Duty Ratio" falls in a second allowable range (e2≤On-Duty Ratio≤L %) (step **S117**). The second allowable range has a lower limit value e2 which is a positive value smaller than L %.

If the "On-Duty Ratio" falls in the second allowable range, then adjuster **117** finishes the light source control process.

If the "On-Duty Ratio" does not fall in the second allowable range, then adjuster **117** judges whether or not the "On-Duty Ratio" is smaller than the lower limit value e2 of the second allowable range (step **S118**).

If the "On-Duty Ratio" is smaller than the lower limit value e2, then adjuster **117** decides that the junction temperature Tj is too high and outputs a light source control signal representative of the "On-Duty Ratio" to light source driver **109**R.

Adjuster **117** thus changes the duty ratio of light source **103**R to the "On-Duty Ratio" calculated in step S**116** (step S**119**).

Thereafter, adjuster **117** outputs a cooler control signal representative of the amount of applied cooler electric power that is greater than the predetermined amount of applied cooler electric power described above to cooler driver **108**R, which increases the amount of cooler electric power (step S**120**).

Since the case temperature Tc of light source **103**R drops due to the increase in the amount of applied cooler electric power, adjuster **117** calculates an "On-Duty Ratio" of light source **103**R again back in step S**114**. If the calculated "On-Duty Ratio" falls in the second allowable range in step S**117**, then the light source control process is ended.

If adjuster **117** decides that the "On-Duty Ratio" is greater than the lower limit value e2 of the second allowable range in step S**118**, then adjuster **117** decides that the "On-Duty Ratio" is greater than the upper limit value of L % of the second allowable range, and outputs a cooler control signal representative of amount of applied cooler electric power that is smaller than the predetermined amount of applied cooler electric power described above to cooler driver **108**R. Adjuster **117** thus reduces the amount of applied cooler electric power and hence the amount of cooling power of cooler **107**R (step S**121**).

Since the case temperature Tc of light source **103**R rises due to the reduction in the amount of applied cooler electric power, adjuster **117** sets the "On-Duty Ratio" of light source **103**R to L % back in step S**114**. Thereafter, adjuster **117** calculates an "On-Duty Ratio" of light source **103**R again in step S**116**. If the calculated "On-Duty Ratio" falls in the second allowable range in step S**117**, then the light source control process is ended.

If adjuster **117** decides that the detection result L is equal to or smaller than the second threshold value in step S**113**, then adjuster **117** outputs a light source control signal representative of a duty ratio=50% (second threshold value) to light source driver **109**A, which energizes light source **103**R at the level of brightness which is 50% of the maximum brightness (step S**122**).

When light source **103**R is energized, light source case temperature detector **112**R detects a case temperature Tc of light source **103**R and outputs it to adjuster **117**. Light source forward voltage detector **113**R detects a forward voltage Vf of light source **103**R and outputs it to adjuster **117**. Light source forward current detector **114**R detects a forward current If of light source **103**R and outputs it to adjuster **117** (step S**123**).

When adjuster **117** receives the case temperature Tc, the forward voltage Vf, and the forward current If, it outputs the case temperature Tc, the forward voltage Vf, the forward current If, and the characteristic information read in step S**102** to On-Duty-Ratio calculator **116**.

When On-Duty-Ratio calculator **116** receives the characteristic information, the case temperature Tc, the forward voltage Vf, and the forward current If, it calculates an "On-Duty Ratio" of light source **103**R based on the characteristic information, the case temperature Tc, the forward voltage Vf, and the forward current (step S**124**). The "On-Duty Ratio" is calculated in the same manner as it is calculated in step S**107**.

After having calculated the "On-Duty Ratio" of light source **103**R, On-Duty-Ratio calculator **116** outputs the calculated "On-Duty Ratio" to adjuster **117**. When adjuster **117** receives the "On-Duty Ratio", it judges whether the "On-Duty Ratio" falls in a third allowable range (e3≤On-Duty Ratio≤50%) or not (step S**125**). The third allowable range has a lower limit value e3 which is a positive value that is smaller than 50%.

If the "On-Duty Ratio" falls in the third allowable range, then adjuster **117** ends the light source control process.

If the "On-Duty Ratio" does not fall in the third allowable range, then adjuster **117** judges whether or not the "On-Duty Ratio" is smaller than the lower limit value e3 of the third allowable range (step S**126**).

If the "On-Duty Ratio" is smaller than the lower limit value e3, then adjuster **117** decides that the junction temperature Tj is too high and outputs a light source control signal representative of the "On-Duty Ratio" to light source driver **109**R. Adjuster **117** thus changes the duty ratio of light source **103**R to the "On-Duty Ratio" calculated in step S**124** (step S**127**).

Thereafter, adjuster **117** outputs a cooler control signal representative of the amount of applied cooler electric power that is greater than the predetermined amount of applied cooler electric power described above to cooler driver **108**R, which increases the amount of cooler electric power (step S**128**).

Since the case temperature Tc of light source **103**R drops due to the increase in the applied amount of cooler electric power, adjuster **117** calculates an "On-Duty Ratio" of light source **103**R again back in step S**123**. If the calculated "On-Duty Ratio" falls in the second allowable range in step S**125**, then the light source control process is ended.

If adjuster **117** decides that the "On-Duty Ratio" is greater than the lower limit value e3 of the third allowable range in step S**126**, then adjuster **117** decides that the "On-Duty Ratio" is greater than the upper limit value of 50% of the third allowable range, and outputs a cooler control signal representative of amount of applied cooler electric power that is smaller than the predetermined amount of applied cooler electric power described above to cooler driver **108**R. Adjuster **117** thus reduces the amount of applied cooler electric power and hence the amount of cooling power of cooler **107**R (step S**129**).

Since the case temperature Tc of light source **103**R rises due to the reduction in the amount of applied cooler electric power, adjuster **117** sets the "On-Duty Ratio" of light source **103**R to 50% back in step S**122**. Thereafter, adjuster **117** calculates an "On-Duty Ratio" of light source **103**R again in step S**124**. If the calculated "On-Duty Ratio" falls in the third allowable range in step S**125**, then the light source control process is ended.

The amount of applied cooler electric power in projection-type display apparatus **100** according to the present exemplary embodiment shown in FIG. **2** will be evaluated.

It is assumed hereinbelow that the red LED, the green LED, and the blue LED which are used respectively in light sources **103**R, **103**G, **103**B have the characteristics (the maximum junction temperature Tj(max), the power conversion efficiency WPE, and the thermal resistance Rj−c between the LED junction and the LED case) shown in FIG. **7**. It is also assumed that the Peltier devices that are used respectively in the coolers **107**R, **107**G, **107**B have the characteristics shown in FIGS. **8** and **9**. FIG. **8** shows endothermic characteristics representative of the relationship between the current I and endothermic quantity Q of a Peltier device at the time the heat radiation side has a temperature of 50° C., and FIG. **9** shows current vs. voltage characteristics representative of the relationship between the current I and voltage V of the Peltier device at the time when the heat radiation side has a temperature of 50° C.

It is assumed that after the power supply of projection-type display apparatus **100** is turned on, the detection result L of light sensor **111** represents the first threshold value "100" or greater, and adjuster **117** energizes light source **103**R with a pulsed voltage having a duty ratio=100%. It is also assumed

that the detection result L from light sensor **111** thereafter changes to a value smaller than the third threshold value "50", and adjuster **117** energizes light source **103**R with a pulsed voltage having a duty ratio=50%, and that the detection result L from light sensor **111** goes back to the first threshold value "100" or greater, and adjuster **117** energizes light source **103**R with a pulsed voltage having a duty ratio=100%.

FIG. **10** is a diagram showing time-dependent changes in the junction temperature Tj of light source **103**R, time-dependent changes in the case temperature Tc of light source **103**R, and time-dependent changes in the amount of electric power applied to cooler **107**R at the time projection-type display apparatus **100** performs the above process.

When adjuster **117** is to energize light source **103** with a pulsed voltage having a duty ratio=100%, if the forward voltage Vf of light source **103**R is 3.5 V and the forward current If of light source **103**R is 30 A, then the maximum case temperature which is the case temperature Tc at which the junction temperature Tj becomes the maximum junction temperature Tj(max) is given as follows:

The maximum case temperature of the red LED=20° C.≈110° C.−300 W×0.35×(1−0.15)×1° C./W

The maximum case temperature of the green LED=40° C.≈170° C.−300 W×0.45×(1−0.05)×1° C./W

The maximum case temperature of the blue LED=115° C.≈170° C.−300 W×0.2×(1−0.1)×1° C./W

The amount of electric power applied to the Peltier device for the red LED, for example, in order to keep the case temperature Tc as the maximum case temperature of 20° C. is calculated as follows:

The amount of electric power applied to the Peltier device=128 W≈7.5 A×17 V

When adjuster **117** is to energize light source **103** with a pulsed voltage having a duty ratio=50%, if the forward voltage Vf of light source **103**R is 3.5 V and the forward current If of light source **103**R is 30 A, then the maximum case temperature of light source **103**R is given as follows:

The maximum case temperature=65° C.≈110° C.−3.5 V×30 A×0.5×(1−0.15)×1

The amount of electric power applied to the Peltier device for the red LED, for example, in order to keep the case temperature Tc as the maximum case temperature of 65° C. is calculated as follows:

The amount of electric power applied to the Peltier device=4.5 W=1.5 A×3 V

The amount of applied cooler electric power in projection-type display apparatus **200** shown in FIG. **1** will be evaluated.

As is the case with each of the LEDs of projection-type display apparatus **100** shown in FIG. **2**, each of the LEDs of projection-type display apparatus **200** has the characteristics shown in FIG. **7**. As with the Peltier devices of projection-type display apparatus **100**, the Peltier devices that are used in coolers **205**R, **205**G, **205**B of projection-type display apparatus **200** have the characteristics shown in FIGS. **8** and **9**.

It is assumed that after the power supply of projection-type display apparatus **200** is turned on, the detection result L of light sensor **202** represents the first threshold value "100" or greater, and adjuster **201** energizes light source **204**R with a pulsed voltage having a duty ratio=100%. It is also assumed that the detection result L from light sensor **202** thereafter changes to a value that are smaller than the third threshold value "50", and adjuster **201** energizes light source **103** with a pulsed voltage having a duty ratio=50%, and that the detection result L from light sensor **202** goes back to the first threshold value "100" or greater, and adjuster **201** energizes light source **103** with a pulsed voltage having a duty ratio=100%.

FIG. **11** is a diagram showing time-dependent changes in the junction temperature Tj of light source **204**R, time-dependent changes in the case temperature Tc of light source **204**R, and time-dependent changes in the electric power applied to cooler **205**R at the time projection-type display apparatus **200** performs the above process.

When the red LED is energized with a pulsed voltage having a duty ratio=100%, as projection-type display apparatus **200** keeps the case temperature Tc as the maximum case temperature of 20° C., the electric power applied to the Peltier devices of projection-type display apparatus **200** is the same as the amount of electric power applied to the Peltier devices of projection-type display apparatus **100**. When the red LED is energized with a pulsed voltage having a duty ratio=50%, however, since projection-type display apparatus **200** keeps the case temperature Tc as the maximum case temperature of 20° C., the amount of electric power applied to the Peltier devices of projection-type display apparatus **200** is given as follows:

The amount of electric power applied to the Peltier devices=60 W=5 A×12 V

Therefore, if the detection result L from light sensor **202** is L>200, then the amount of electric power applied to the Peltier devices of projection-type display apparatus **200** shown in FIG. **1** is the same as the amount of electric power applied to the Peltier devices of projection-type display apparatus **100**. However, if the detection result L from light sensor **202** is L<50, then the amount of electric power applied to the Peltier devices of projection-type display apparatus **200** shown in FIG. **1** is greater than the amount of electric power applied to the Peltier devices of projection-type display apparatus **100**.

According to the present exemplary embodiment, as described above, cooler **107**R cools light source **103**R. Light sensor **111** detects the brightness of the surrounding area. Light source case temperature detector **112**R detects the case temperature which represents the temperature of the case of light source **103**R. Light source forward voltage detector **113**R detects the forward voltage of light source **103**R. Light source forward current detector **114**R detects the forward current of light source **103**R. Adjuster **117** adjusts the brightness of light source **103**R based on the brightness of the surrounding area, and also adjusts the amount of cooling power of cooler **107**R based on the forward voltage, the forward current, and the case temperature.

Consequently, the amount of cooling power is adjusted based on the forward voltage, the forward current, and the case temperature. Since the amount of applied light source electric power W can be grasped from the forward voltage and the forward current, the amount of electric power involved in the cooling of the LEDs can be of an appropriate value even when the amount of applied light source electric power is adjusted.

In the exemplary embodiment described above, the illustrated configuration is by way of example only, and the present invention is not limited to the illustrated configuration.

For example, although coolers **107**R, **107**G, **107**B are illustrated as comprising Peltier devices, they may comprise cooling devices other than Peltier devices insofar as the amount of

their cooling power can be adjusted depending on the amount of electric power applied thereto.

DESCRIPTION OF REFERENCE CHARACTERS

100 projection-type display apparatus
101 image signal processor
102 spatial light modulation signal generator
103R, **103**G, **103**B light source
104R, **104**G, **104**B spatial light modulator
105 cross dichroic prism
106 projection lens
107R, **107**G, **107**B cooler
108R, **108**G, **108**B cooler driver
109R, **109**G, **109**B light source driver
110 light sensor driver
111 light sensor
112R, **112**G, **112**B light source case temperature detector
113R, **113**G, **113**B light source forward voltage detector
114R, **114**G, **114**B light source forward current detector
115 memory
116 On-Duty-Ratio calculator
117 adjuster

The invention claimed is:

1. A display apparatus for projecting a beam from an LED to display an image, the display apparatus comprising:

a cooler that cools said LED;

a light detector that detects brightness of a surrounding area;

a voltage detector that detects a forward voltage of said LED;

a current detector that detects a forward current of said LED;

a temperature detector that detects a case temperature which represents a temperature of a case of said LED; and

a controller that adjusts brightness of said LED based on the brightness of the surrounding area and adjusts an amount of cooling power of said cooler based on said forward voltage, said forward current, and said case temperature,

wherein said controller calculates a ratio of a difference between a predetermined maximum junction temperature and said case temperature to a difference between a junction temperature of said LED and said case temperature, based on said forward voltage, said forward current, and said case temperature.

2. The display apparatus according to claim **1**, wherein, if said ratio is greater than an upper limit of an allowable range determined depending on the brightness of said LED, said controller reduces said amount of cooling power, and if said ratio is smaller than a lower limit of said allowable range, said controller increases said amount of cooling power.

3. The display apparatus according to claim **2**, wherein, if said ratio is smaller than said lower limit, said controller adjusts the brightness of said LED depending on said ratio.

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